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Article

Macrophytobenthos stock in the protected water areas of Sevastopol city

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Abstract. For the first time, the stocks of bottom vegetation at the natural monuments of Sevastopol city were assessed on the basis of hydrobiological studies (2020–2021). The largest total macrophyte stock and their dominant species (*Ericaria crinita* and *Gongolaria barbata*) are typical for the water area of the natural monument "Nearshore Aquatic Complex (NAC) at Cape Lucullus", the lowest, for "NAC at Cape Sarych". Maximum biomass stock of *Phyllophora crispa* algae was recorded in the waters of the natural monument "NAC at Tauric Chersonese". The results obtained may be recommended for optimizing the environmental regime of the natural monuments.

Keywords: protected areas, Black Sea, macrophytes, *Ericaria crinita*, *Gongolaria barbata*, *Phyllophora crispa*

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Научная статья

Запасы макрофитобентоса охраняемых акваторий города Севастополя

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Аннотация. Впервые рассчитаны запасы донной растительности памятников природы г. Севастополя на основе проведенных гидроботанических исследований (2020-2021 гг.). Показано, что наибольшие общие запасы макрофитов и входящих в их состав доминирующих *Ericaria crinita*, *Gongolaria barbata* характерны для акватории памятника природы «Прибрежный аквальный комплекс (ПАК) у мыса Лукулл», наименьшие - для «ПАК у мыса Сарыч». Максимальный запас фитомассы *Phyllophora crispa* отмечен в акватории памятника природы «ПАК у Херсонеса Таврического». Полученные результаты могут быть рекомендованы для оптимизации природоохранного режима памятников природы.

Ключевые слова: особо охраняемые природные территории, Черное море, макрофиты, *Ericaria crinita*, *Gongolaria barbata*, *Phyllophora crispa*

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Introduction

Marine protected areas (MPAs) play an important role in preserving the landscape and biological diversity of the coastal zone. Nowadays, there are 31 MPAs protected in accordance with state legislation, international agreements and conventions in the coastal area of the Crimean Peninsula (Pankeeva et al., 2022). Currently, protected areas (PAs) of Sevastopol city are represented by fourteen PAs of different protection categories with a total area of 25021.3 hectares, of which 24350.4 hectares are terrestrial and 670.9 hectares are aquatic, which is 23.1 and 3.1% of the land and water area of the city, respectively. In Sevastopol city, there are 6 MPAs: four natural monuments and two wildlife sanctuaries (Pozachenyuk et al., 2020). Marine natural monuments were established in Sevastopol in 1972–1979 with the total water area of 345.2 hectares (51.5% of the total protected water area in the region). In the coastal natural monuments of Sevastopol, *Cystoseira*[1] (here, and further on, *Ericaria–Gongolaria*) and *Phyllophora* communities, being the keystone of the Black Sea ecosystem and having a high conservation status in the seas of Europe, carry both high scientific and environmental value (Gubbay et al., 2016).

Modern conditions of the Black Sea basin are characterized by significant restructuring and degradation of bottom biocenoses, so a reduction in the stocks of bottom vegetation and dominant algae species are recorded almost everywhere, i.e., both in the coastal anthropogenically transformed areas and in protected water areas. At the same time, many researchers note a significant decrease in the resource potential of macrophytobenthos in the lower subtidal zone (Maksimova and Luchina, 2002; Milchakova et al., 2011; Mironova et al., 2007a, b, 2009; Vilkova, 2005). In this regard, taking into account the increasing eutrophication of the aquatic environment, affecting coastal ecosystems, the assessment of macrophyte stocks as the main primary producers acquires high scientific, practical and environmental significance and serves as the basis for rational environmental management.

In recent years, significant information has been accumulated on the species composition of macrophytobenthos and landscape diversity in MPAs of the coastal zone of Crimea (Evstigneeva and Tankovskaya, 2021; Milchakova et al., 2015; Osobo okhranyaemye..., 2020; Pankeeva and Mironova, 2022a, b; Pankeeva et al., 2021; Sadogursky et al., 2019). However, data on the state of the Black Sea macrophyte resources and their production characteristics for MPA are still scarce (Milchakova et al., 2011; Mironova et al., 2007a, 2009; Vilkova, 2005).

In this regard, the study aims to assess the stocks of bottom vegetation and the plant biomass reserves of the dominant algae species and to analyze the distribution of macrophyte stocks in the water areas of natural monuments of Sevastopol city.

Materials and methods

Hydrobiological studies in the coastal zone of natural monuments (“Nearshore Aquatic Complex (NAC) at Cape Sarych”, “NAC at Cape Fiolent”, “NAC at Tauric Chersonese”, and “NAC at Cape Lucullus”) were carried out in July–August of 2020 and 2021(Table 1, Fig. 1).

The sampling was performed by snorkeling and on board of small vessels. In order to study the macrophytobenthos species composition and to assess the stocks of bottom vegetation within the boundaries of each natural monument, three transects were set, located perpendicular to the shoreline (Fig. 1). Station coordinates were determined using a portable GPS receiver (Oregon 650). Sampling was carried out according to generally accepted methods (Kalugina-Gutnik, 1969). Four sampling areas (25×25 cm) were set at each depth (0.5, 1, 3, 5, 10 and 15 m), the diver visually assessed the projective coverage of the bottom with macrophytes (PC). In total, 12 transects with 65 stations were set, at which 260 quantitative samples of macrophytobenthos were collected and processed. The algae were placed in the fine mesh bags and delivered immediately to the laboratory. In laboratory, algae were identified by the accepted taxonomic keys (Zinova, 1967), taking into account the most recent taxonomy (AlgaeBase[2]). The wet weight and biomass of dominant species of the Black Sea (*Ericaria crinita* (Duby) Molinari & Guiry, *Gongolaria barbata* (Stackhouse) Kuntze, and *Phyllophora crispa* (Hudson) P.S. Dixon), of lithophytes and epiphytes, and the total wet biomass of macrophytes were deter-

[1] Earlier, these two species were referred to the same genus of *Cystoseira*: *Ericaria crinita* (Duby) Molinari & Guiry = *Cystoseira crinita; Gongolaria barbata* (Stackhouse) Kuntze = *Cystoseira barbata*

[2] AlgaeBase. World-wide electronic publication, National University of Ireland, Galway, Ireland. Electronic resource. URL: https://www.algaebase.org (access date: March 2, 2023).

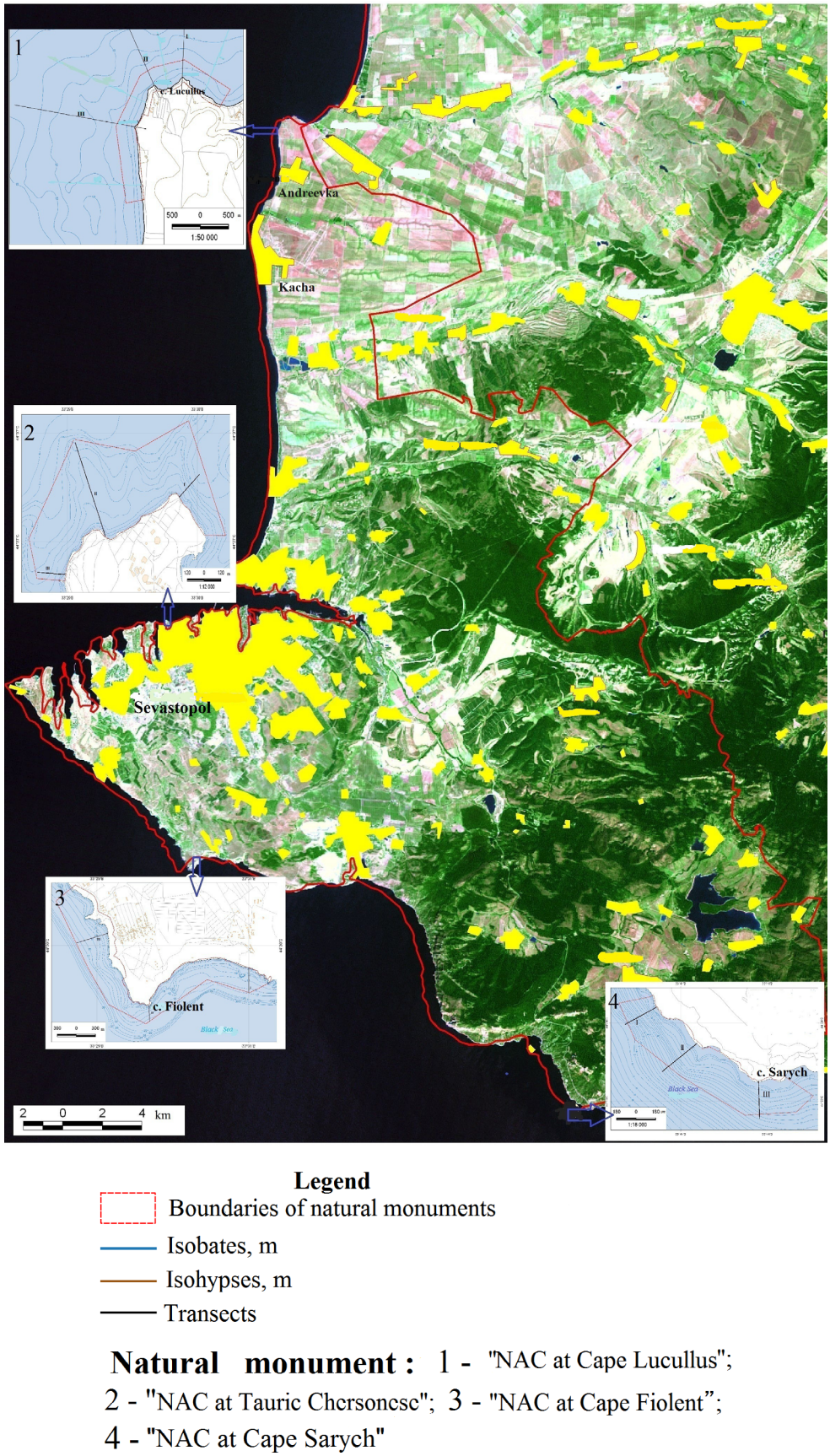

Fig. 1. Schematic map of the geographical location of the study areas.

Table 1. Marine natural monuments of regional significance of Sevastopol city.

Name of protected area	Area, ha			Depth, m (within the boundaries of natural monuments)	Year of creation
	Total	Terrestrial	Aquatic		
“NAC at Cape Sarych”	62.28	3.51	58.77	0.5–15	1972
“NAC at Cape Fiolent”	179.40	66.0	113.4	0.5–15	1972
“NAC at Tauric Chersonese”	60.66	1.00	59.66	0.5–15	1979
“NAC at Cape Lucullus”	128.58	15.12	113.46	0.5–5	1979
Total	**430.92**	**85.63**	**345.29**		

mined. The algae were carefully blotted with filter paper, large forms were weighed on a KRUPS scale with a 0.01 g accuracy, small forms, on a VK-600 scale with a 0.001 g accuracy. Macroalgae resources (kg, wet weight) were calculated using the formula modified for marine research:

$$Q = B \times PC \times S / 100,$$

where Q is the stock of macrophytes (kg); B – the average biomass of algae ($kg \cdot m^{-2}$) in the thickets; PC – the projective coverage of the bottom by macrophytes (%); S – the area occupied by thickets of macrophytes, m^2 (Blinova et al., 2005).

The bottom slope angle did not exceed 0.06, so it was not taken into account when calculating macrophyte stocks (Mironova and Pankeeva, 2021). The water area was determined using the QGIS 2.14.18 program. In order to obtain comparable data, the total stocks of macrophytobenthos and the dominant algal species were recalculated per unit area (hectare). For this purpose, we have introduced the parameter of the plant biomass stock. The plant biomass stock (tons per hectare) was calculated as the ratio of the stock of *Ericaria*–*Gongolaria* and *Phyllophora* macrophytes (Q) to the area of the area occupied by bottom vegetation (S) (Mironova et al., 2007b).

Results and discussion

Based on the conducted research, bottom vegetation reserves are assessed and uneven distribution of macrophytes and dominant algae species by depth is shown for four natural monuments of Sevastopol city. In general, in the water area of all natural monuments, macrophytobenthos characterized by a belt type of distribution with a dominance of *Ericaria*–*Gongolaria* (*Ericaria crinita* and *Gongolaria barbata;* 0.5–5 (10) m depth) and *Phyllophora* (*Phyllophora crispa;* 5–10 (15) m depth) belts.

“**NAC at Cape Sarych**”

This natural monument locates in the southern part of Sevastopol. The coastal zone is characterized by a deep slope composed of coarse sediments down to a 10 m depth. Starting from 3 m depth, mosaic pebble-gravel with shelly ground is noted. Sandy bottom with gravel and crushed stones with shelly ground are recorded below 10 m depth.

The phytal width does not exceed 40 m. PC reaches 90–100% at a 0.5–5.0 m depth, but does not exceed 90% at a 5–15 m depth. *Ericaria crinita* dominates in the bottom plant communities at a 0.5–3.0 m depth; *Phyllophora crispa* occurs at a 3–5 m depth among *Ericaria crinita* and *Gongolaria barbata* thickets*. Phyllophora crispa* dominates at 5–15 m depth*.*

The total macrophyte stock is estimated at 2232.8 tons, varying from 180.3 to 636.4 tons depending on the depth (Fig. 2**A**). The largest macrophyte reserve is recorded at a 3–5 m depth, the lowest, at a 10–15 m depth (Table 2). On average, 55.8 tons of macrophytes are located per hectare.

Ericaria crinita and *Gongolaria barbata* stocks amount to 1360.9 tons. The most productive thickets of these species are confined to a 3–5 m depth. Significant reserves of *Ericaria crinita* and *Gongolaria barbata* are also found at the depths from 1 to 3 m and from 5 to 10 m. In the lower sublittoral zone (10–15 m depth), this value decreases significantly. *Ericaria crinita* and *Gongolaria barbata* contribution to total macrophyte stock decreases with increasing depth from 68–70% down to 27%.

Phyllophora crispa stock is estimated at 319.1 tons. The share of *Phyllophora crispa* increases with depth from 2% (1–3 m depth) to 21–60% (5–15 m depth). The *Phyllophora* reserves changes in a similar way from 1.5 to 12.3 t·ha^{-1} in the same depth range.

"**NAC at Cape Fiolent**"

This nearshore aquatic complex is located in the southwestern part of Sevastopol. The underwater slope is deep. At a 3–10 m depth, blocks predominate; clearings are filled predominantly with gravel and pebble deposits. There are small islands, reefs, and steep, pointed cliffs along the coastline. In the depth range of 10–15 m and deeper, the bottom is represented by sand-gravel-pebble sediments. The phytal width varies from 80 to 450 m. In the coastal zone of Cape Fiolent and adjacent slopes, PC increases from 10–20 up to 50–60% along with the depth increase from 0.5 to 10 m. *Ericaria crinita* and *Gongolaria barbata* dominate in the bottom vegetation. At a depth of 10–15 m, PC is 50%; here, *Phyllophora crispa* dominates.

The total macrophyte stock is 3716.3 tons. The maximum value is noted at a 5–10 m depth, the minimum, at a 1–3 m depth (Fig. 2**B**). On average, 38.7 tons of macrophytes grow per hectare; the plant biomass increases from 46.4 to 63.7 t·ha^{-1} in the depth range from 0.5 to 5.0 m, but then decreases to 15.3 t·ha^{-1} as the depth reaches 15 m (Table 2).

Ericaria crinita and *Gongolaria barbata* stocks are estimated at 2513.6 tons, varying at different depths from 271.8 to 812.6 tons in accordance to the dynamics of the total macrophyte reserves. *Ericaria crinita* and *Gongolaria barbata* share decreases from 79 down to 64% with increasing depth from 0.5 to 10 m, but at a 10–15 m depth it increases up to 78% of the total macrophyte reserves.

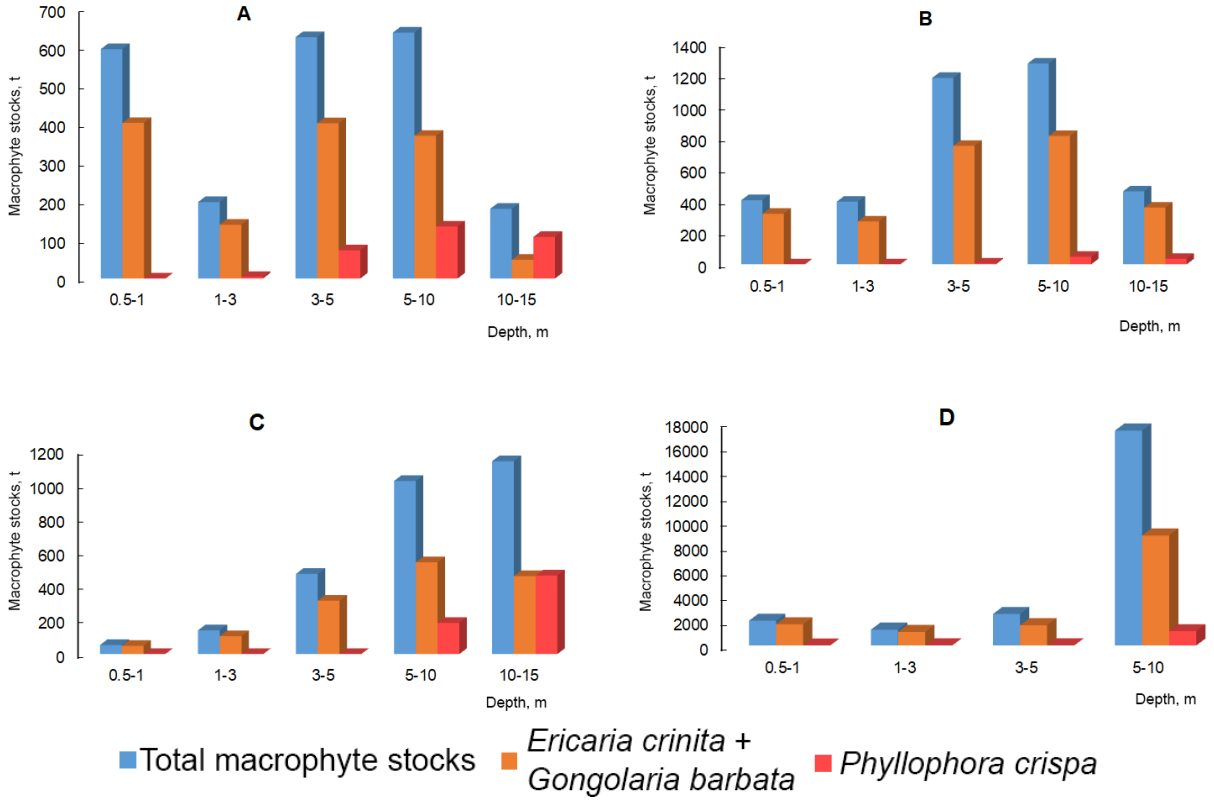

Fig. 2. Dynamics of macrophyte stocks and of the dominant algae species in regard to the water depth at the natural monuments of Sevastopol city in summer of 2020 and 2021. **A** – "NAC at Cape Sarych", **B** – "NAC at Cape Fiolent", **C** – "NAC at Tauric Chersonese", **D** – "NAC at Cape Lucullus".

Table 2. Dynamics of macrophyte biomass stock, the dominant algae species and their share in the total stocks of macrophytobenthos (by depth) in the water area of natural monuments of Sevastopol city in summer of 2020 and 2021.

Depth, m	Area, ha	Macfophyte biomass stock, t·ha^{-1}	*Ericaria crinita* + *Gongolaria barbata*		*Phyllophora crispa*	
			Biomass stock, t·ha^{-1}	Share in stock, %	Biomass stock, t·ha^{-1}	Share in stock, %
“NAC at Cape Sarych”						
0.5–1	9.7	61.4	41.6	68	0	0
1–3	2.8	71.2	49.9	70	1.5	2
3–5	7.2	86.4	55.6	64	10.1	12
5–10	10.9	58.2	33.8	58	12.3	21
10–15	9.4	19.2	5.1	27	11.4	60
“NAC at Cape Fiolent”						
0.5–1	8.8	46.4	36.5	79	0	0
1–3	6.6	60.4	41.4	69	0	0
3–5	18.5	63.7	40.5	64	0.3	0
5–10	31.9	39.8	25.5	64	1.5	4
10–15	30.2	15.3	11.9	78	1.1	8
“NAC at Tauric Chersonese”						
0.5–1	1.2	43.6	34.3	79	0	0
1–3	2.4	59.1	44.4	75	0	0
3–5	7.9	59.7	39.7	67	0	0
5–10	20.7	49.2	26.1	53	8.9	18
10–15	26.6	42.6	17.2	40	17.3	41
“NAC at Cape Lucullus”						
0.5–1	28.9	53.6	46.2	86	0	0
1–3	18.4	70.3	60.0	85	0	0
3–5	52.4	48.4	31.0	64	0.1	0
Outside the borders of “NAC at Cape Lucullus”						
5–10	433.9	40.9	21.2	52	3.1	8

Phyllophora crispa stock is insignificant (87.6 tons), its thickets are sparse and confined mainly to a 5–15 m depth, where 94% of this species' stock is located in the coastal zone of the natural monument. The *Phyllophora* reserve at these depths ranges as 1.1–1.5 t·ha^{-1}, its contribution to the total macrophyte stock does not exceed 4–8%.

"**NAC at Tauric Chersonese**"

This natural monument occupies the northwestern part of Sevastopol. In the coastal waters, there is a stone bench, represented by a prepared layer of limestone, covered with rounded boulders. At a depth of 3–10 m, a rugged relief formed, complicated by a pile of limestone blocks. A sand belt locates deeper, giving way to a wide belt of shelly ground, beyond which the slope drops steeply. The bottom is represented by silt deposits. The phytal width varies from 160 to 360 m. PC are low (40–50%) in the depth range of 0.5–5.0 m. *Ericaria crinita* and *Gongolaria barbata* dominate in macrophyte cover. At a 5–10 m depth, PC does not exceed 50%. Here, *Phyllophora crispa* dominates.

The total macrophyte stock is 2815.7 tons, increasing more than an order of magnitude (from 53.2 to 1133.9 tons) as the depth increases from 0.5 to 15 m (Fig. 2**C**). On average, 47.9 tons of macrophytes are registered per hectare. The maximum macrophyte reserve is noted at a 1–5 m depth, the minimum, at the 0.5–1.0 m and 10–15 m depths (Table 2).

Ericaria crinita and *Gongolaria barbata* stocks are estimated at 1457.2 tons together, with 68% located at a 5–15 m depth. The largest reserve is recorded at a 1–5 m depth. Moving from the upper to the lower sublittoral zone (0.5–15 m depth), the contribution of *Ericaria crinita* and *Gongolaria barbata* is reduced by half (from 79 to 40%).

Significant accumulations of *Phyllophora crispa* are observed at a depth range of 5 to 15 m, where almost 100% of its stock is found. Near the lower boundary of the phytal, in a comparable depth range, the share of *Phyllophora* to the total macrophyte stock increases from 18 to 41%. Its reserves change in a similar way, from 8.9 to 17.3 t·ha^{-1}.

"**NAC at Cape Lucullus**"

This nearshore aquatic complex locates at the northern tip of Sevastopol. In the coastal waters near the cape, there are numerous slabs and blocks of conglomerates, which form protrusions of the bottom down to a 5 m depth. Between the capes, the underwater slope is shallow, composed of sandy deposits and characterized by small riffles (ripple marks). At a 5–6 m depth, a clear bend of the underwater slope is observed. The deeper area is occupied by a block-boulder pile; in the clearings, gravel-sand bottom sediments with shelly ground are noted. The phytal width varies from 400 to 1600 m. Close to the capes, PC increases from 20–40 up to 90% along with the depth increase from 0.5 to 5 m. *Ericaria crinita* and *Gongolaria barbata* dominate in the macrophyte community. PC decrease from 70–90 down to 30–40% as the depth increase from 5 to 10 m. Here, *Phyllophora crispa* prevails.

The total macrophyte stock within the boundaries of the natural monument (0.5–5.0 m depth) reaches 5379.3 tons. The maximum reserves are recorded in the middle sublittoral zone (3–5 m depth), the minimum, in the upper sublittoral zone (1–3 m depth) (Fig. 2**D**). On average, 53.9 tons of algae grow per hectare, with the largest reserves of plant biomass noted at a 1–3 m depth (Table 2).

Ericaria crinita and *Gongolaria barbata* stocks are estimated at 4064.1 tons with most productive accumulations at the depths of 3–5 m. *Ericaria crinita* and *Gongolaria barbata* reserves vary from 31.0 to 60.0 t·ha^{-1} with a maximum at a 1–3 m depth and a minimum at a 3–5 m depth. Their share in total macrophyte stock decreases with increasing depth from 86 down to 64%.

Phyllophora crispa stock is insignificant (5.5 t), of which 89% are located at a 3–5 m depth. The biomass reserves do not exceed 0.1 t·ha^{-1}.

Therefore, the total macrophyte stock varies from 2232.8 to 5379.3 tons, of particular species *Ericaria crinita* and *Gongolaria barbata,* from 1360.9 to 4064.1 tons, in the coastal zone of the studied natural monuments. The maximum values ae noted in the water area of the natural monument "NAC at Cape Lucullus", the minimum, at "NAC at Cape Sarych". *Phyllophora crispa* stocks in the study areas vary in a wide range from 5.5 to 644.9 tons, with their largest value recorded in the water area of the natural monument "NAC at Tauric Chersonese", the lowest, at "NAC at Cape Lucullus".

The distribution of algae in regard to the water depth is influenced by the light penetration and, therefore, illumination level, necessary for the photosynthesis (Kalugina-Gutnik, 1975). Illumination level is known to vary along a depth gradient; as the depth increases, a typical change in plant communities is observed, the quantitative indicators of macrophytobenthos biomass decrease, which is common for the coastal zone of all natural monuments (Table 2).

The differences in total macrophyte stock and of the stocks of *Ericaria crinita* and *Gongolaria barbata* are minor in the water area of the studied natural monuments in the upper sublittoral zone (depth 0.5–3 m). At "NAC at Cape Sarych", "NAC at Cape Fiolent", and "NAC at Tauric Chersonese", these indicators range from 43.6 to 71.2 t·ha^{-1} and from 34.3 to 49.9 t·ha^{-1}, respectively, at "NAC at Cape Lucullus", from 53.6 to 70.3 t·ha^{-1} and from 46.2 to 60.0 t·ha^{-1}, although the bottom area in this depth range of the first three natural monuments varies from 3.6 to 15.4 hectares, and on the fourth, it reaches a significant value and amounts to 47.3 hectares (Table 2).

For the coastal zone of all natural monuments, the largest share of dominant *Ericaria crinita* and *Gongolaria barbata* in the total macrophyte stock is recorded at a 0.5–3.0 m depth, where its contribution varies from 68 to 86%. At the same time, the maximum values of this indicator are recorded in the water area of "NAC at Cape Lucullus", the minimum, at "NAC at Cape Sarych". Currently, the Crimean coast of the Black Sea is characterized by a displacement of the main thickets of macrophytes and their key species *Ericaria crinita* and *Gongolaria barbata* to a shallower depth, although previously the ecological-phytocoenotic optimum of these species was at a 3–5 m depth (Kalugina-Gutnik, 1975; Milchakova et al., 2011; Mironova et al., 2007a, 2009).

In the waters of the natural monuments "NAC at Cape Sarych", "NAC at Cape Fiolent", and "NAC at Tauric Chersonese", the maximum macrophyte stock and maximum stock of *Ericaria crinita* and *Gongolaria barbata* are recorded at a 3–5 m depth*,* varying within the range of 59.7–86.4 and 40.5–55.6 t·ha^{-1}, respectively (Table 2). In the water area of the "NAC at Cape Lucullus", these indicators are slightly lower (48.4 and 31.0 t·ha^{-1}, respectively).

In the coastal zone of the studied natural monuments, the decrease of macrophyte stock and that of *Ericaria crinita* and *Gongolaria barbata* is noted as the depth increases from 5 to 15 m ("NAC at Cape Sarych" in 3.0 and 6.6 times, respectively; "NAC at Cape Fiolent", 2.6 and 2.1 times; "NAC at Tauric Chersonese", 1.1 and 1.5 times). At "NAC at Cape Lucullus", these indicators have decreased by 1.2 and 1.5 times, respectively, along with the depth increase from 5 to 10 m (Table 2). Such differences are probably associated both with illumination changes and with the peculiarities of the geological and geomorphological structure of the underwater slope and its morphometric characteristics. These assumptions are supported by the earlier studies, where it has been reported that the features of the bottom topography and the geological and morphological structure of the underwater slope have a significant impact on the density of distribution of bottom vegetation, changes in the structural elements and production characteristics of communities (Ignatova et al., 2014; Simakova, 2009; Vilkova, 2005). In addition, much attention has been paid to the differences in species diversity and biomass of macrophytobenthos, which depended on the geological and geomorphological structure of the shores of two nearby capes on the Tarkhankut Peninsula (Sadogursky, 2018).

Regard must be paid to the distribution of macrophyte stocks and of *Ericaria crinita* and *Gongolaria barbata*, which are influenced by the composition of bottom sediments. In the water area of the natural monuments "NAC at Cape Sarych", "NAC at Cape Fiolent", and "NAC at Tauric Chersonese" coarse sediments predominate at a 0.5–1.0 m depth; under conditions of high hydrodynamic activity in these areas, they prevent and complicate the attachment of algae thalli to this type of substrate (Goryachkin and Dolotov, 2019). This explains the lower values of total macrophyte stock and that of *Ericaria–Gongolaria* at this depth range compared with similar indicators at a 1–3 m depth (Table 2). The coastal zone of "NAC at Cape Lucullus" is composed predominantly of sandy sediments with bedrock outcrops at a 0.5–1.0 m depth, which are confined to capes, leading to a decrease in the amount of total macrophyte stock and of *Ericaria crinita* and *Gongolaria barbata* (Table 2). In the water area of the studied natural monuments, the highest macrophyte stocks and that of *Ericaria–Gongolaria* belt have been recorded a 1–5 m depth, where the substrates are more suitable for the attachment and growth of macroalgae.

The underwater slope in the water area of natural monuments in the lower sublittoral zone (5–15 m depth) is flattening, and the size–weight composition of bottom sediments changes. Along with block-boulder deposits, there are sandy and gravel-pebble bottom sediments, which precondition the distribution of *Phyllophora crispa.* This species has not been found in the waters of natural monuments at a 0.5–3.0 m depth (except "NAC at Cape Sarych"); the main thickets of *Phyllophora crispa* locate at the depths less than 5 m. Maximum stock of *Phyllophora* is registered in the water area of the natural

monuments “NAC at Cape Sarych” and “NAC at Tauric Chersonese”, where at a 5–15 m depth they vary from 8.9 to 17.3 t·ha^{-1}; in the water area of “NAC at Cape Fiolent” and “NAC at Cape Lucullus”, these values are significantly lower (0.1–1.5 t·ha^{-1}). *Phyllophora crispa* shares from 4 to 60% of the total macrophyte stock in the coastal zone of natural monuments, increasing its contribution as the depth increases from 5 to 15 m.

Currently, the lower depth limit of growth of many deep-sea algae species, including *Phyllophora crispa*, is being observed. In recent years, numerous communications are reported about its mass habitat along the Caucasian and Crimean shelves at a 3–10 m depth instead of the typical 25–30 m depth, while the stocks of the species have decreased by more than three times (Maksimova and Luchina, 2002; Milchakova et al., 2011; Mironova et al., 2007a, 2009; Simakova, 2009; Vilkova, 2005). Probably, a decrease in water transparency and an increase in the degree of eutrophication are the reasons for the negative impact on shade-loving species of macroalgae.

The obtained data on macrophytobenthos resources may be used to substantiate scientifically the boundaries of the protected water area of natural monuments in Sevastopol city. In the early 1970s–1980s, during establishing of a network of protected areas in Crimea and Sevastopol city, a kind of territorial "quota" was defined for marine natural monuments of regional significance, which was ~ 300 m wide from the coastline to the sea. However, there is no scientific grounds for such value for each specific protected water area of natural monuments, so these limits require significant re-assessment (Pankeeva et al., 2021).

Significant macrophyte stock and that of keystone species *Ericaria crinita, Gongolaria barbata,* and *Phyllophora crispa* (17736.5, 9210.2, and 1147.7 tons, and reserves of 40.9, 21.2, and 3.1 t·ha^{-1}, respectively) locate at a depth of 5–10 m in the water area of the “NAC at Cape Lucullus”, which is an area not included into the boundaries of this natural monument. In order to optimize the environmental regime, it makes sense to include this part of the marine area additionally to this natural monument. A water area of 627 hectares has been proposed recently for inclusion in the natural monument “NAC at Cape Lucullus” (Milchakova et al., 2022).

According to the materials of coastal expeditions conducted in the coastal zone of Sevastopol in the summer period of 1997–2015, the total macrophyte stock is estimated at 84.2 thousand tons, of which 50.2 thousand tons are accounted for by *Ericaria crinita* and *Gongolaria barbata,* 4.8 thousand tons, on *Phyllophora crispa,* and less than 1 ton, for *Zostera* species (Mironova and Pankeeva, 2016). The total water area of Sevastopol city is 21.6 thousand hectares, of which the protected marine part of natural monuments is 345.3 hectares (Pozachenyuk et al., 2020).

In the water area of the natural monuments “NAC at Cape Sarych” and “NAC at Cape Fiolent”, bottom vegetation is distributed over a smaller area comparing to the total MPA. In this regard, the total area of the surveyed marine part of the natural monuments did not exceed 294.3 ha, or 1.4% of the total water area of Sevastopol city (Table 1). However, according to calculated data, significant macrophyte stock and its keystone species are concentrated in this MPA. *Ericaria crinita, Gongolaria barbata,* and *Phyllophora crispa* contribute 17.3, 19.4 and 22% of the total macrophyte stock of Sevastopol city, respectively. Among the studied natural monuments, the largest macrophyte stock and the stocks of *Ericaria crinita* and *Gongolaria barbata* are registered in the waters of the natural monument “NAC at Cape Lucullus” (6.9 and 8.8%, respectively), *Phyllophora crispa,* at “NAC at Tauric Chersonese” (12.5% of the total macrophyte stock of Sevastopol city).

Regard must be paid to the natural monuments of Sevastopol city, which are characterized by high values of macrophyte resources, a significant degree of preservation of *Ericaria–Gongolaria* and *Phyllophora* phytocenoses. *Ericaria crinita* and *Gongolaria barbata* are included in the Red List of the Republic of Crimea, *Phyllophora crispa* into the Red Lists of the Russian Federation, the Republic of Crimea, and of Sevastopol city (Krasnaya kniga..., 2008, 2015, 2018). However, low conservation status of surveyed natural monuments does not allow preservation of bottom vegetation in full (Aleksandrov and Milchakova, 2022). With a scientifically based approach, it is necessary to upgrade the category of their environmental status in the future. The studied natural monuments are distinguished by their isolated location in the coastal zone and the small area of the sea part. In order to ensure the conservation and optimal functioning of protected areas in Sevastopol city, it is necessary to treat the protected areas as the complex ecological network, but not the isolated objects (Pankeeva et al., 2021).

Conclusions

1. For the first time, the total macrophyte stock and the reserves of their keystone species *Ericaria crinita* and *Gongolaria barbata* have been assessed in the water area of natural monuments of Sevastopol city. The maximum stocks were registered in the coastal zone of the "NAC at Cape Lucullus", the minimum, in the water area of the "NAC at Cape Sarych". The largest stocks of *Phyllophora crispa* were registered at the "NAC at Tauric Chersonese", the lowest, at the "NAC at Cape Lucullus".

2. The analysis of the dynamics of macrophyte stock and dominant algae species by depth allows to conclude that:

– in the water area of the studied natural monuments, the stock of plant biomass macrophytes and their keystone species *Ericaria crinita* and *Gongolaria barbata* is the highest at the 1–5 m depths, in the coastal zone "NAC at Cape Lucullus", the highest values are recorded at the 1–3 m depths;

– in the water area of natural monuments "NAC at Cape Sarych" and "NAC at Tauric Chersonese", the maximum plant biomass of *Phyllophora crispa* is registered; this value is significantly lower in the coastal zone of the "NAC at Cape Fiolent"; a minimal stock of this species is observed in the waters of the "NAC at Cape Lucullus".

3. In the water area of the studied natural monuments, the largest share of *Ericaria crinita* and *Gongolaria barbata* in the total macrophyte stock is recorded at the 0.5–3.0 m depths, reaching its maximum values in the coastal zone of the "NAC at Cape Lucullus", minimum, in the water area of the "NAC at Cape Sarych". *Phyllophora crispa* contribution into total macrophyte stock increases with increasing depth (from 5 to 15 m) in the water area of natural monuments; the highest values are noted at the "NAC at Cape Sarych", the lowest, at the "NAC at Cape Fiolent".

4. Significant reserves of macrophytes, in particular *Ericaria crinita, Gongolaria barbata,* and *Phyllophora crispa,* locate in the waters of natural monuments and constitute 17.3, 19.4, and 22%, respectively, of the total macrophyte stock of Sevastopol city. The largest reserves of macrophytes *Ericaria crinita* and *Gongolaria barbata* are registered in the water area "NAC at Cape Lucullus" (6.9 and 8.8%, respectively), of *Phyllophora crispa,* in the coastal zone "NAC at Tauric Chersonese" (12.5% of the total macrophyte stock of Sevastopol city). The data obtained may be used to optimize the environmental regime of the studied natural monuments.

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